MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2016/2017

EEN7026 – SEMICONDUCTOR PHYSICS AND MATERIALS

11 MARCH 2017
2.30 p.m - 5.30 p.m
(3 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 8 pages with 6 Questions only.
2. Attempt **All** questions. The distribution of the marks for each question is given.
3. Please write all your answers in the Answer Booklet provided.

Useful constants and coefficients:

Physical Constants

Boltzmann's constant (k)	1.3807×10^{-23} JK^{-1} 8.617×10^{-5} eVK^{-1}
Planck's constant (h)	6.626×10^{-34} Js
Thermal voltage@300K kT/e kT	0.0259 V 0.0259 eV
Electron mass in free space (m_e)	9.10939×10^{-31}kg
Electron charge (e)	1.60218×10^{-19} C
Effective density of states in the conduction band for Si (N_c)	2.8×10^{19} cm^{-3}
Effective density of states in the Valence band for Si (N_v)	1.2×10^{19} cm^{-3}
Permeability of free space (μ_0)	$4\pi\times10^{-7}$ Hm^{-1}
Permittivity of free space of free space (ε_0)	8.85×10^{-12} Fm^{-1}
Avogadro's number (N_A)	6.022×10^{23} atoms/mol

Question 1 [16 marks]

(a) Use the wave-particle duality principle described by the de Broglie relationship between momentum and wavelength and the classical wave equation to show that the one-dimensional time-independent Schrödinger equation is given by

$$-\frac{\hbar^2}{2m}\frac{\partial^2\psi(x)}{\partial x^2}+V(x)\psi(x)=E\psi(x)$$

[7 marks]

(b) The allowed energy states of an electron in a one-dimensional infinite potential well of length L, where $V(x) = 0$ for $0 < x < L$ and $V = \infty$ elsewhere, is quantized with $E=\frac{\hbar^2\pi^2n^2}{2mL^2}$, and its normalized wave function is $\psi_n(x)=\sqrt{\frac{2}{L}}\sin\left(\frac{n\pi x}{L}\right)$, where n = 1, 2, 3, … . Sketch the first FOUR allowed energy levels, the corresponding wave functions and probability distributions for the electron in this infinite potential well.

[6 marks]

(c) Apply the 3-D version of the Schrödinger equation for an electron confined in a 3-D square potential energy box with zero potential energy inside the box and infinite outside. How many equivalent states are there at energy level E_{443}?

[3 marks]

Continued….

Question 2 [18 marks]

(a) Silicon has the diamond crystal structure with lattice parameter $a = 0.543$ nm and its density is 2.33 gcm^{-3}. Figure Q2(a) shows the planar atomic configuration and channeling in the diamond structure of silicon viewed along [100], [110], and [111] directions, where different shadowing for atoms refers to atoms in different atomic layers.

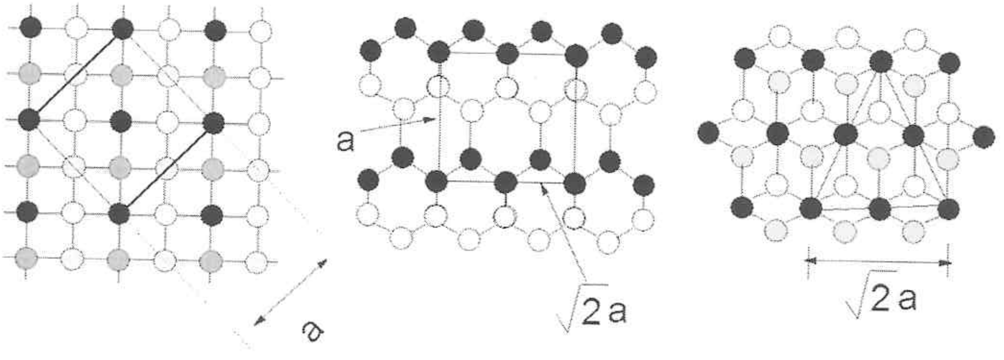

Figure Q2(a)

(i) Sketch the two-dimension (100), (110) and (111) planes in the unit cell and calculate the number of atoms per nm^2 on these planes. [9 marks]

(ii) Which plane has the most number of atoms per nm^2? [1 mark]

(b) There is a 4.2% lattice mismatch between SiGe and Si, the lattice constant of SiGe is bigger, as shown in Figure Q2(b).

(i) Draw the strained SiGe layer formed on Si substrate and briefly explain your diagram. [4 marks]

(ii) Explain why there is a critical thickness for which the strained SiGe layer is formed without defects. [4 marks]

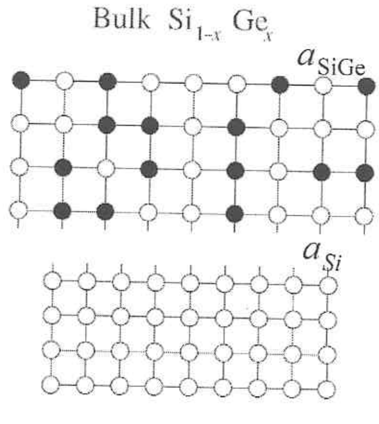

Figure Q2(b)

Continued....

Question 3 [20 marks]

(a) Figure Q3(a) shows the conduction band and valence band of GaAs crystal in the [111] and [100] directions. In the conduction band, there are THREE valleys namely Γ-valley, L-valley and X-valley. The motion of electrons in each valley can be described in a quasi-classical manner through the use of effective mass.

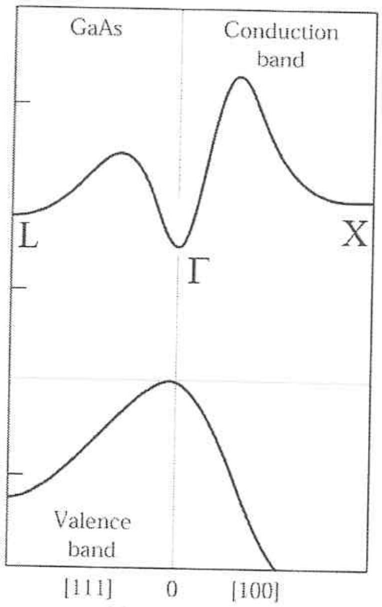

Figure Q3(a)

(i) Electron in which valley will have a heavier effective mass, Γ-valley or L-valley and why? [4 marks]

(ii) With the aid of band diagrams, show the electrons transfer between the valleys in the conduction band and explain the negative differential resistivity observed in N-type GaAs semiconductor. [8 marks]

(b) Explain why the electron transport in an indirect semiconductor like silicon is relatively poor as compare to the direct bandgap semiconductor such as GaAs. [6 marks]

(c) List down FOUR different types of scattering mechanisms occur in a semiconductor. [2 marks]

Continued....

Question 4 [18 marks]

(a) Figure Q4(a) shows the temperature dependence of electron concentration in an extrinsic semiconductor with doping density, $N_D = 10^{15}$ cm^{-3}. With the aid of simple band diagrams, briefly discuss the characteristics of this semiconductor.

[8 marks]

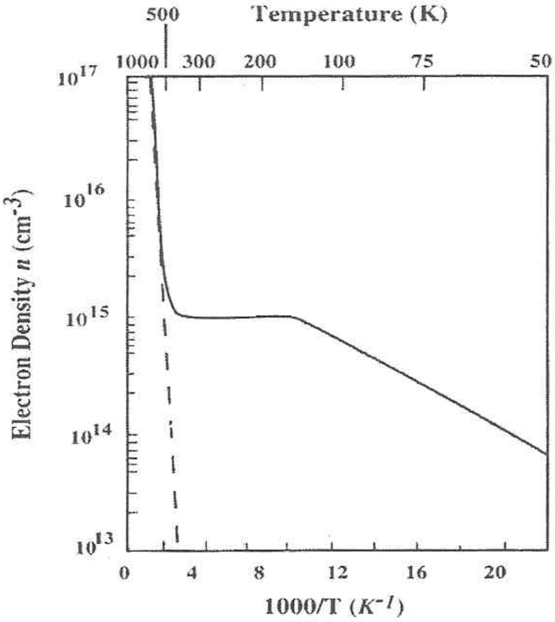

Figure Q4(a)

(b) At a finite temperature, T, the fraction of the electrons that are bound to the donors in an extrinsic semiconductor is given by $\frac{n_d}{n+n_d} = \frac{1}{\frac{N_C}{2N_D}\exp\left(-\frac{E_C - E_d}{k_B T}\right)+1}$, where n_d is the number of electrons attached to the donors, N_D is the donor density, N_C is effective density of state at the conduction bandedge, k_B is the Boltzmann constant, and E_d is the donor ground state from the conduction bandedge E_C. Given that $N_C = 2.8\times10^{19} cm^{-3}$ at 300 K and $N_D = 10^{16} cm^{-3}$.

(i) Determine the fraction of ionized donors if the donor energy is 45 meV below the conduction band.

[3 marks]

(ii) What is the percentage of ionized donors if the doping density is increased to $N_D = 10^{18} cm^{-3}$?

[3 marks]

(c) When the donor is ionized, a fixed positively charged ion is present in the crystal and causes deterioration in the transport properties of electrons. Briefly discuss the method of modulation doping to increase the free electron density in a semiconductor without the present of ionized impurity scattering.

[4 marks]

Continued....

Question 5 [14 marks]

(a) The first transistor was made of germanium (Ge) in 1947, explain why today silicon is the material of choice in integrated circuits (ICs) fabrication.

[4 marks]

(b) The commercial growth of single crystals of Si is mainly by the Czochralski method. Briefly describe the Czochralski process steps to grow the silicon bulk crystal and the main advantages of this method.

[5 marks]

(c) Figure Q5(c) shows the sketch of a Molecular Beam Epitaxy (MBE) chamber; briefly describe this technique for epitaxial growth of semiconductors and its advantages.

[5 marks]

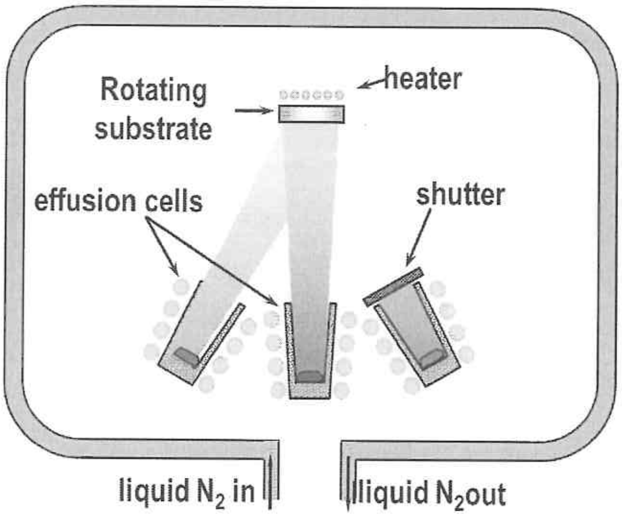

Figure Q5(c)

Continued....

Question 6 [14 marks]

(a) Crystalline defects can be classified into four categories according to their geometry.

(i) Name the four categories and give an example for each category. [4 marks]

(ii) What are the impacts of these defects on semiconductor devices? [1 mark]

(b) Gettering is an important process for enhancing the yield of VLSI manufacturing. With the aid of a simple energy diagram, explain how the gettering process removes the device-degrading impurities from the active circuit regions of the wafer.

[5 marks]

(c) The time-zero-dielectric-breakdown (TZDB) is a technique used in the wafer foundry to evaluate the reliability of gate oxides in Metal Oxide Semiconductor (MOS) devices. The cumulative gate oxide integrity failures of silicon wafer I and II as a function of oxide breakdown field is shown in Figure Q6(c). Identify the main sources of failures for wafer I and II, respectively. Explain your answer.

[4 marks]

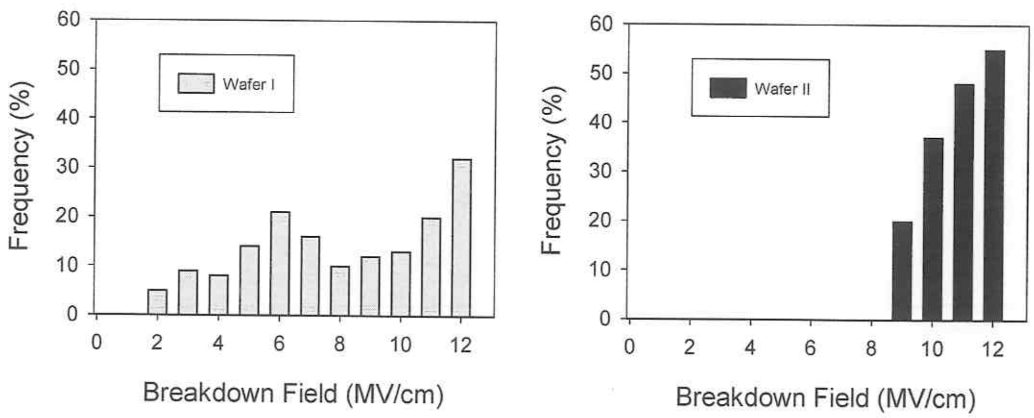

Figure Q6(c)

End of the paper